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Psycho-Motor and Error Enabled Simulations Modeling
Vulnerable Skills in the Pre-Mastery Phase – Medical Practice
Initiative Procedural Skill Decay and Maintenance (MPI-PSD)

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14. ABSTRACT

This term of the grant has been comprised of three main directions. The first primary direction focused on simulation preparation, personnel training, and conducting data collection sessions. Based on recommendations identified from pilot simulations, necessary modifications were made to each of the procedural stations. Next, the entire team traveled to the institutions involved in the study, set up all the simulation stations, interacted with participants, and collected data to bring back to the lab for analysis. The second direction of effort focused on the organization, database and transcription coding, and analysis of this data. Analysis was expedited using participant workbooks, common error checklists, and video recordings made during participant data collections. Additional data such as images of final products were obtained and coded. The third direction focused on the dissemination of findings learned in the initial analyses performed. The development of a Performance Review Tool had its initial completion and distribution to participants based off of the data that was collected. Multiple abstracts and posters were created for surgical conferences attended. These works concentrated on data from hernia port placements, perceptions of skill reduction, motor control in robotic tasks, and prevalence of rule-based errors. Lessons learned from each of the main directions have been incorporated into plans for additional refinements to be made that will ensure continuing study success for our upcoming second year of data collection sessions.

15. SUBJECT TERMS Refined development of simulated procedure stations; Training of personnel in human subjects research for data collection; Completion of data collection from participating institutions; Development and execution of Performance Review Tool; Organization, coding, and transcribing of collected data; Analysis of qualitative survey and quantitative procedure simulation data; Dissemination of results at surgical conferences

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Introduction

The second term of the grant has continued to focus on identifying key differentiating performance factors in the pre-mastery and mastery phases. Identifying these factors was primarily done by evaluating survey results from the first round of data collection, and analyzing performance on two stations. The lab was able to compare performance for current study participants at one station to those whose data was analyzed from previously recorded simulation based LVH repairs. Station design has been optimized to allow for the best possible data collection.

Summary for Statement of Work Progress

The following section details each element of the SoW as it has been addressed through our work thus far. For review, the following four objectives guided this work:

Objective One: To evaluate mental rehearsal as an intervention for skill decay in the pre-mastery phase.

Objective Two: To identify key differentiating performance factors for the pre-mastery and mastery phases.

Objective Three: To develop a generalizable, multi-variable, predictive model of skills decay.

Objective Four: To develop an efficient and effective set of assessment tools and individualized training recommendations to counteract skills decay.

In its second year, our work has continued to focus on Objectives Two and Four because significant progress on these two objectives is required in order to address Objectives One and Three. We intend to continue refining the elements of Objectives Two and Four over the next year while our primary focus will shift towards addressing Objectives One and Three as data analysis continues.

OBJECTIVE ONE

No progress at the time of this report. We plan to address this objective as data collection continues.

OBJECTIVE TWO

The greatest area of progress for Objective Two has been compiling the data collected in 2014 and conducting analyses. During data collection common error checklists were completed, and the checklists were later used to code and timestamp key events or errors using video collected from each clinical scenario station. Videos from each station were also coded for the major steps that occurred in each participant's procedure. Additionally, standardized final product images of the artificial skin from the laparoscopic ventral hernia (LVH) station were obtained (Figures 1-2). The images were taken from a standard height and position so that each image could be analyzed for the two-dimensional location of stitches or ports placed by the participant.

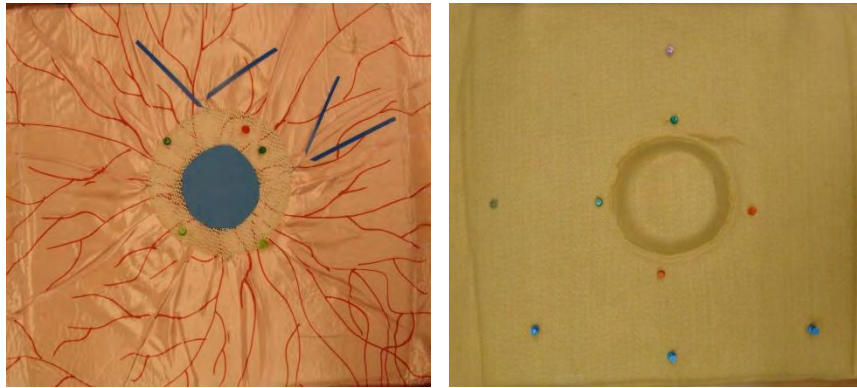


Figure 1-2: Example of completed final product skin from laparoscopic ventral hernia station

Quantifying laparoscopic port placement using position clustering

Participants indicated laparoscopic port placements on surveys administered at data collection sessions. The team later analyzed the data to calculate the distances from the selected placements of ports to the edges of the hernia defects (Figure 3). An abstract was submitted to the Academic Surgical Conference (ASC) (Rutherford, D.N., D'Angelo, A.D., Kwan, C., Barlow, P.B., & Pugh, C.M., 2014) and was accepted for a podium presentation. Our data indicated a significant difference in the variances of placements for four different hernia types. Residents had the least amount of variance for an epigastric hernia and the most variance within an inguinal hernia.

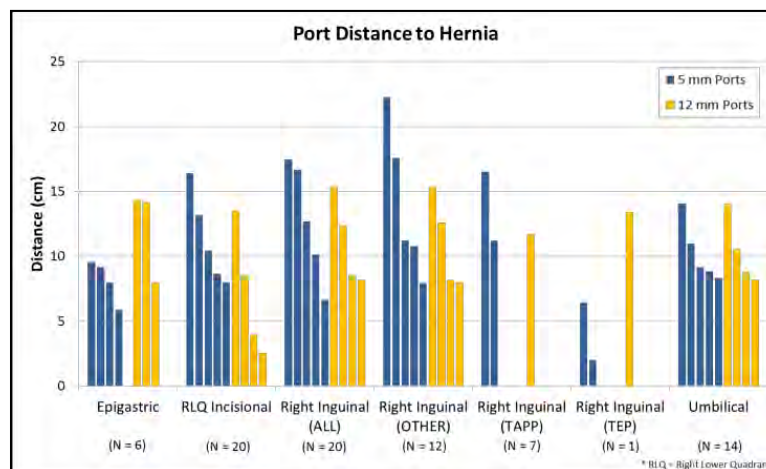


Figure 3: Results from hernia port placement surveys. Distances of ports from the edge of the hernia defect are listed by hernia and procedure option.

Perception of Skill Reduction during Dedicated Research Time

At data collection, participants rated their perceived levels of difficulty with and confidence in performing the simulated clinical scenarios, as well as the perceived reduction in their skills with time spent away from clinical practice in a lab setting. The team later analyzed the survey results and submitted an abstract to ASC (Ray, R.D., Barlow, P.B., D'Angelo, A.D., Pugh, C.M., 2014). The abstract was accepted for a podium presentation at the meeting and a corresponding manuscript is under review the Journal of Surgical Research (D'Angelo, A.D., Ray, R.D., Jenewein, C.G., Jones, G.F., Pugh, C.M., Under review). Results showed that residents who were less confident in performing the presented procedures also perceived their skills would be more greatly reduced by time spent in the lab (Figure 4). However, this was not true for the

laparoscopic ventral hernia (LVH) station; residents may perceive their initial skills to be so low that time in the lab would not reduce skills further.

	Mean (SD)			
	LVH	Bowel Anastomosis	Subclavian Central Line Insertion	Urinary Catheter Placement
Perceived Difficulty ^a	3.56 (1.09)***	3.04 (0.94)***	1.96 (0.79)***	1.16 (0.38)***
Perceived Confidence ^b	2.00 (1.12)*	2.32 (1.22)*	3.56 (0.92)*	4.24 (0.72)*
Perceived Reduction ^c	2.75 (1.14)	2.96 (0.98)	2.04 (0.77)**	1.50 (0.52)***

*p<.05; **p<.01; ***p<.001
^a5-point Likert scale: 1=Not difficult, 5=Extremely difficult
^b5-point Likert scale: 1=Not confident, 5=Extremely confident
^c5-point Likert scale: 1=No reduction, 5=Very large reduction

Figure 4: Table of comparisons of participants' perceived difficulty, confidence, and reduction in skills for each of the simulated clinical procedures performed

Error Tolerance during the laparoscopic ventral hernia repair

In the first year, the team developed and refined an error framework for laparoscopic hernia repair using data from previously recorded resident performance on simulation-based LVH repairs (Figure 2). The team conducted further analyses on this data in this second year. Coordination errors were used to assess the relationship to total errors and error tolerance. An abstract was submitted and accepted as a podium presentation to the American College of Surgeons Accredited Education Institutes (ACS-AEI) consortium meeting (Gwillim, E.C., D'Angelo, A.D., Law, K.E., Cohen, E.R., Rutherford, D.N., Pugh, C.M., 2015) with a corresponding paper under review to the Journal of Surgery (Gwillim, E.C., Law, K.E., Rutherford, D.N., D'Angelo, A.D., Minkoff, E.C., Pugh, C.M., Under review). Results showed residents committed an average of 15.45 (SD=4.61) errors overall and 1.70 (SD=2.25) coordination errors. There was a significant correlation between total errors and coordination errors ($r(18)=0.572$, $p=0.008$).

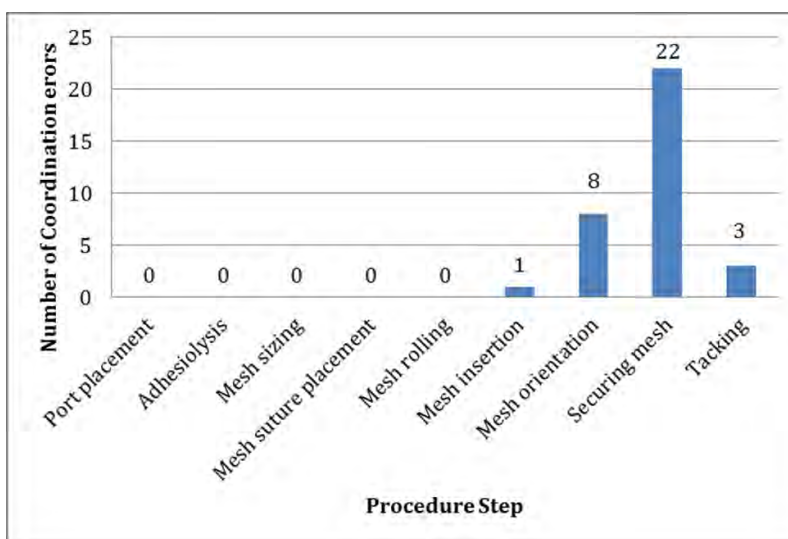


Figure 5: The number of coordination errors per procedure step

Rule-based errors during the laparoscopic ventral hernia repair

The team compared suture and fixation errors committed during the LVH repair. Resident performance on the LVH station was compared to the error analyses conducted in the first year. An abstract was submitted and accepted for a poster presentation to the Association for Surgical Education (ASE) meeting (Law, K.E., D'Angelo, A.D., Ray, R.D., Pugh, C.M., 2015). Results showed the majority of junior residents (87.5%) made at least one error relating to transfascial suture or tacker fixation. Of the seven errors committed by the junior residents, three errors were most prevalent: (1) failure to cut skin prior to inserting suture passer; (2) use of same hole in peritoneum to pull up 2nd suture; and (3) failure to tie or secure sutures prior to tacking ($F(1,30)=32.69$, $p<.001$) (Figure 6). Analysis of the senior resident data revealed similar error types and error occurrence of two of the three the most prevalent errors.

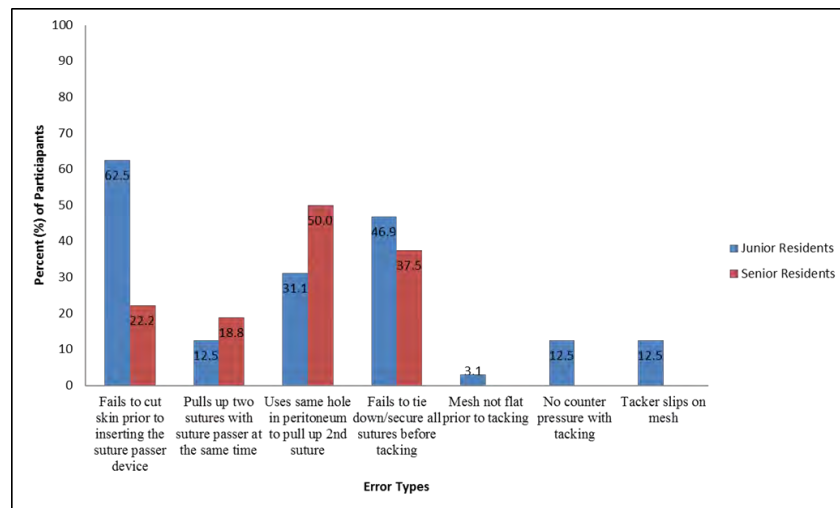


Figure 6: Proportion of participants (%) committing errors during LVH repair

Motor control in a simulated task

At one station, participants performed a simulated surgery task by controlling the movement of a handle of a force-feedback device (Figure 7). The distance of movement overshoot following the puncture event was analyzed based on task conditions and with respect to learning over the course of trials. The abstract was submitted and accepted as a poster presentation to International Conference on Intelligent Robots and Systems (IROS) (Huang, FC., 2014). Results indicated participants were able to recover performance within each trial block despite changes to tissue conditions. Regression analysis showed that overshoot distance changed with respect to trials significantly in each block with greatest change in the initial block ($m=-1.8$ mm/trials, $CI:-2.3,-1.2$) (Figure 8). Secondly, we also found that performance was significantly disrupted at transitions between blocks only when the stiffness was increased. Overshoot increased at transitions between blocks 2-3 (mean: 8.6mm $CI: 6.4, 10.7$), and 3-4 (change: 6.3mm $CI: 3.0, 9.6$), but did not achieve significance for blocks 1-2 (mean: 1.8mm $CI: -0.8, 4.4$).

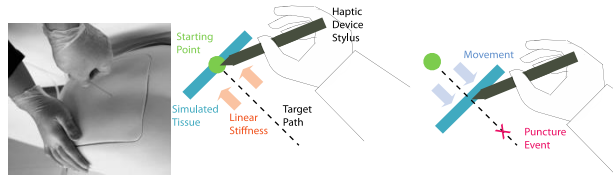


Figure 7: Controlling a haptic device, participants stretched a virtual tissue along a target line. The goal was to puncture the tissue while minimizing movement overshoot following the puncture event.

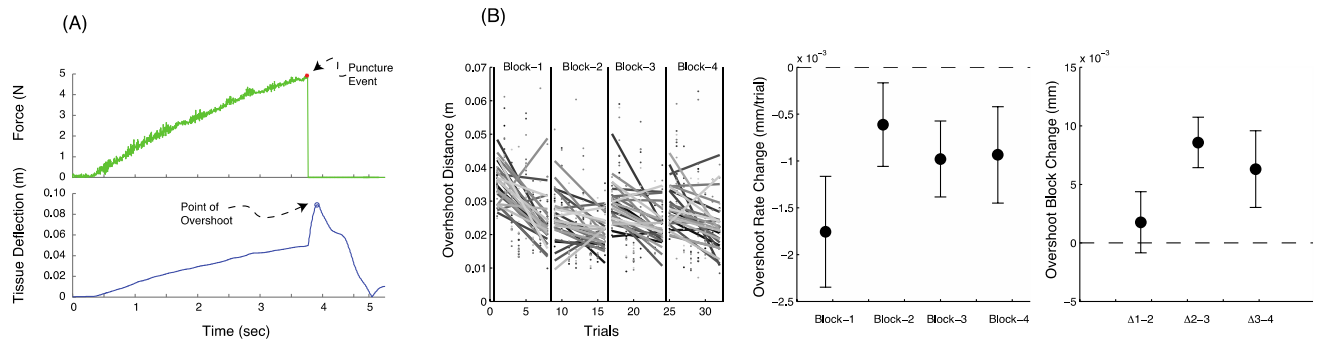


Figure 8: (A) Force and deflection plots for one trial of a simulated tissue puncture task. The tissues stiffness is constant until a threshold force is reached at which point the force is immediately zero. The trial performance was computed as the distance at maximum overshoot with respect to the location of the puncture event. (B) Participants were presented with 32 trials of a simulated puncture task, in 8 blocks with varying force thresholds. Overshoot distance (OD) decreased significantly in each block (left), as indicated by regression slope values (center). The change between blocks (right) indicated a significant disruption in performance only between 2-3 and 3-4. Error bars indicated 95% CI.

OBJECTIVE THREE

No progress at the time of this report. We plan to address this objective as data collection and analysis continues.

OBJECTIVE FOUR

Data Collection Efforts

The primary focus of the study team's efforts surrounded acting on lessons learned from previous pilot studies, training lab personnel, and streamlining current study protocols all in an effort to maximize the quality of the data collected from our participants. Most notably, this process included three distinct features:

- 1) Redesigning the clinical procedure stations;
- 2) Improving existing study protocols/instructions; and
- 3) Providing standardized training *and* assessment for all lab personnel who will be involved in data collection.

Redesigning the Clinical Procedure Stations

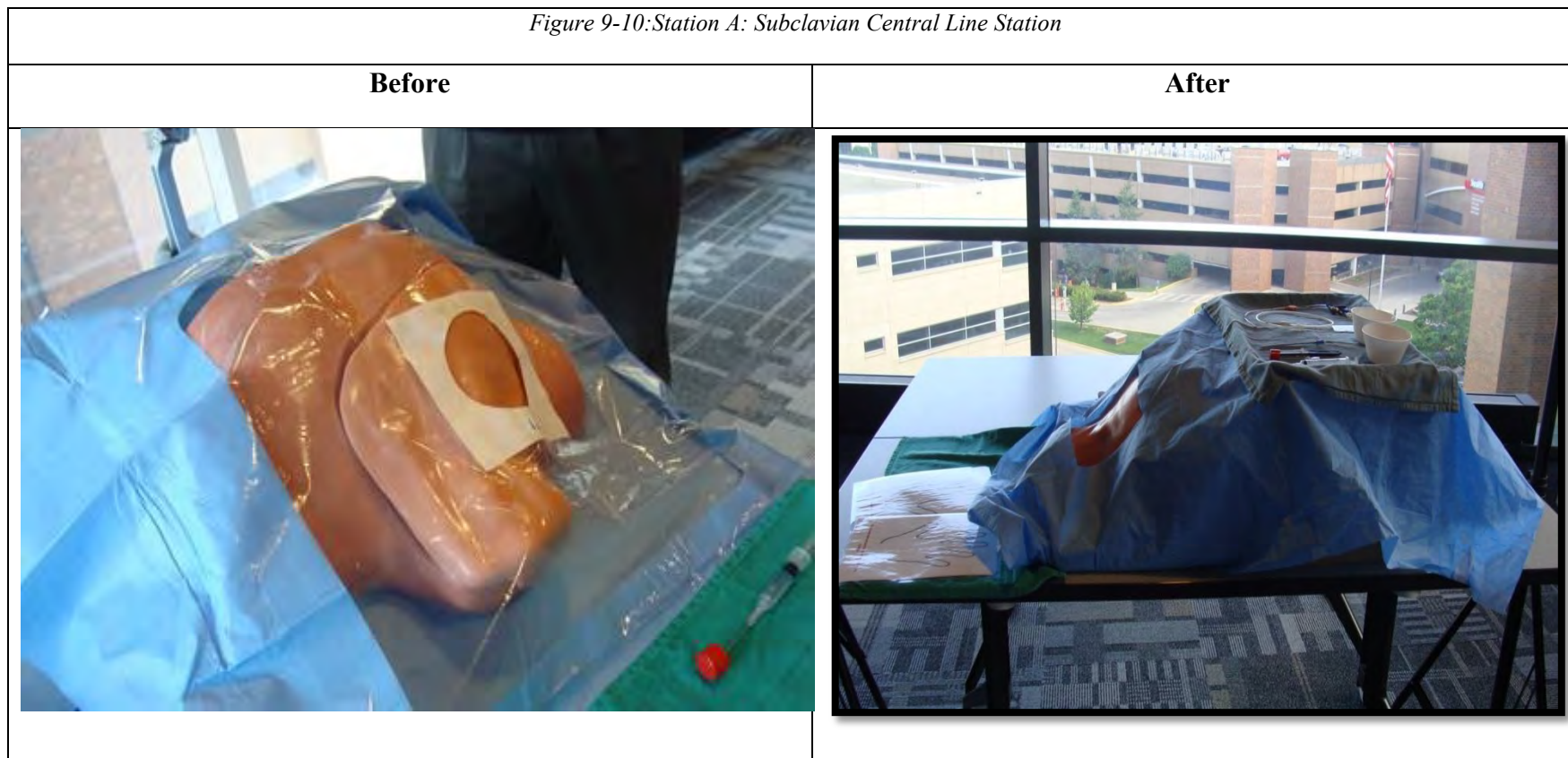
Based on feedback from previous pilots, expert reviews of each station, and internal evaluation, each of the clinical procedure stations underwent a significant improvement over the course of quarter 1.

First, noted “experts” on each of the four clinical procedure stations (Central Line, Bowel Anastomosis, Urinary Catheterization, and Laparoscopic Ventral Hernia) were asked to provide their feedback and suggestions for how each station may be improved. For each review, the expert was asked a series of semi-formal interview questions by project management both before *and* after performing the procedure (Figures below for examples). The audio and video from these expert reviews were transcribed and coded to generate a list of possible improvements or changes to the four stations.

The second major improvement to the clinical procedure stations was consolidating and simplifying the setup of each station. The following examples show some of the improvements made to each station.

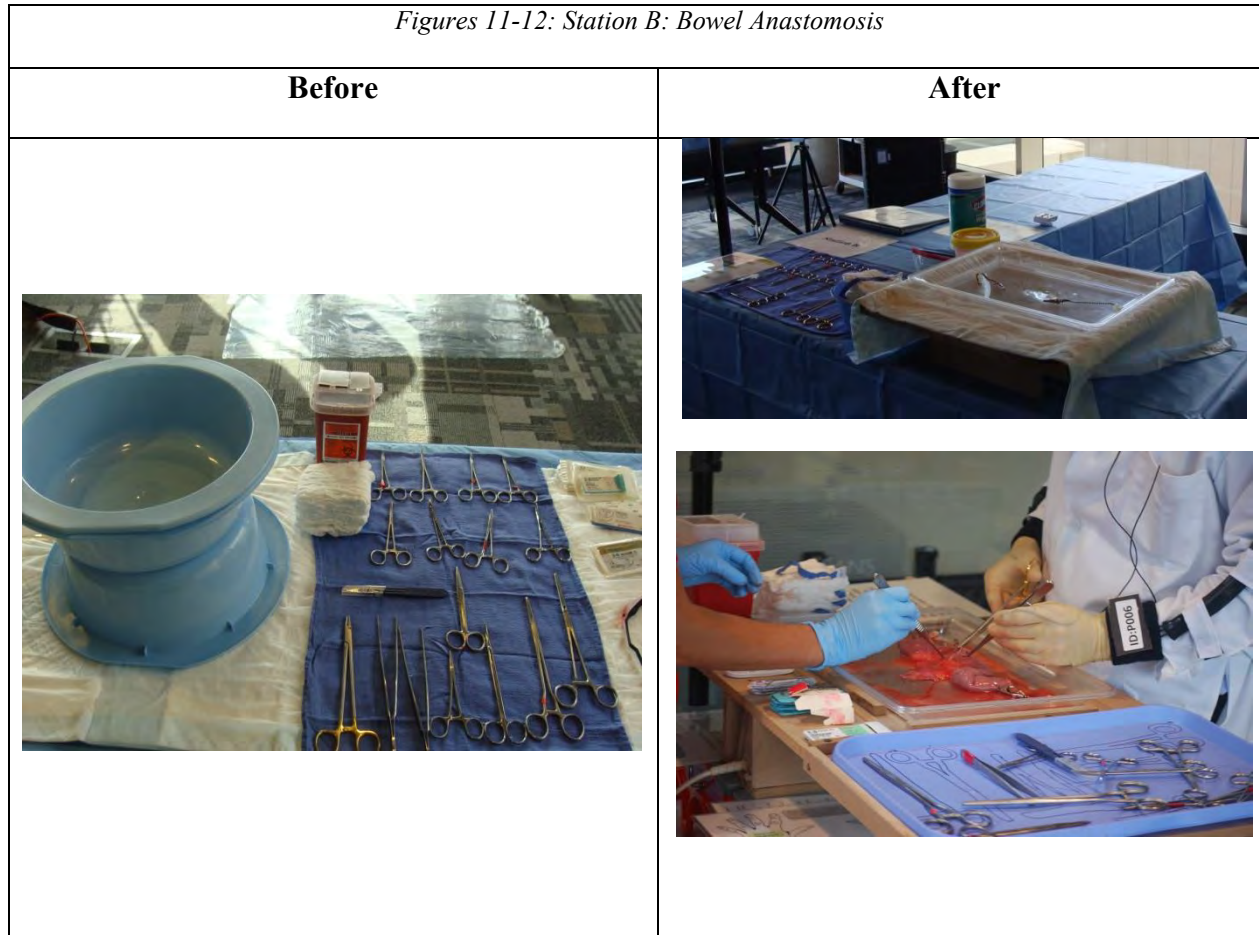
Station A: Subclavian Central Line. The station originally used a blue foam wedge that propped the simulator in a Trendelenberg position with the instruments to the participant's left. The expert mentioned it would be very unlikely that someone would organize their procedure space in such a way, and that the instruments would usually be either on the patient's chest or on a mayo stand to the physician's *right*. A wooden fixture was developed to address this challenge, so that the instruments could be placed on a tray in a location that simulated either the chest or a Mayo stand

Figure 9-10: Station A: Subclavian Central Line Station



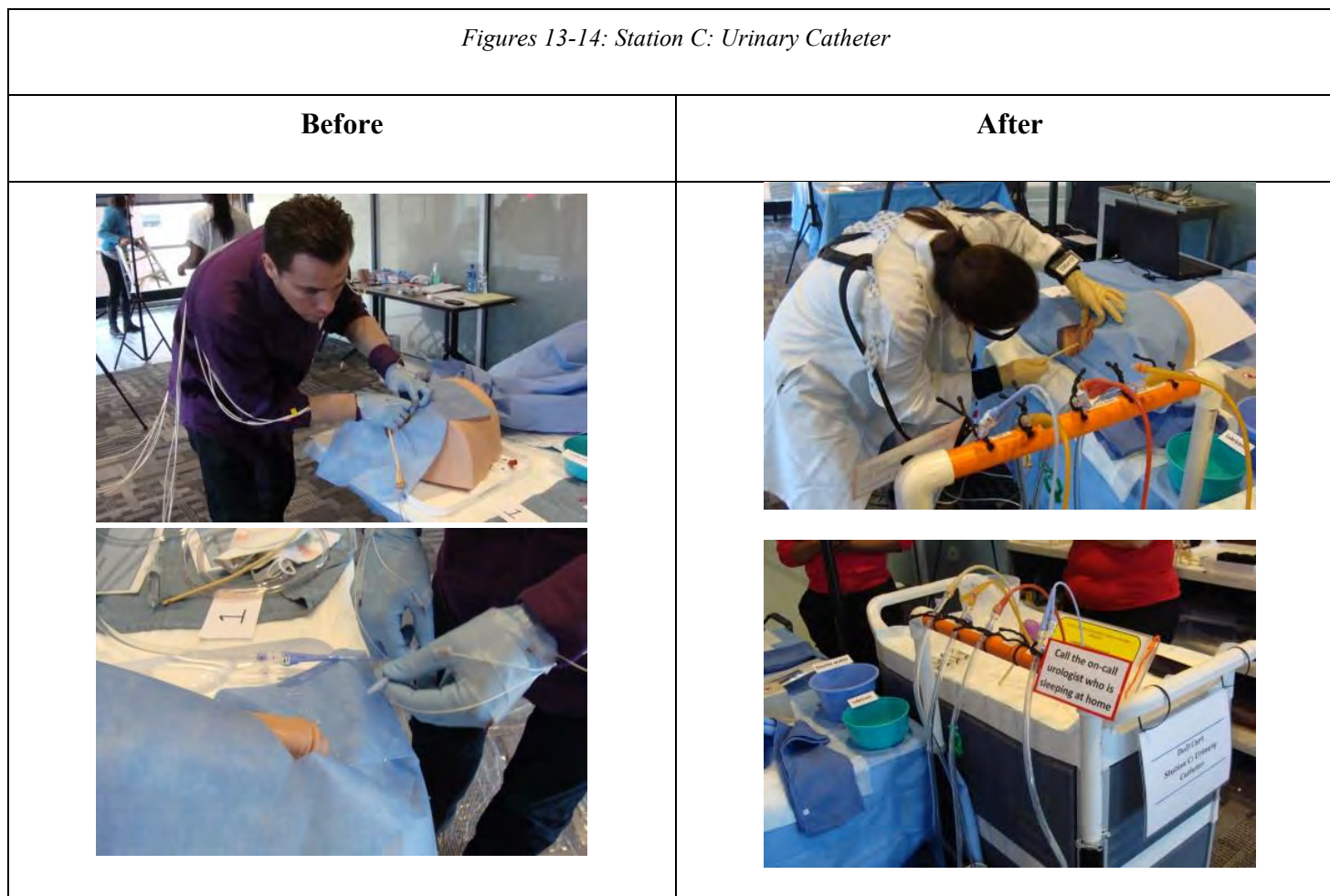
Station B: Bowel Anastomosis. This station also received heavy alterations based on the expert feedback. Figure 11 and 12 shows the before and after images of the station where the small blue basin has been replaced with a raised (and height adjustable) flat tray. The tray also includes two “clips” that hold the bowel segment against the tray as the bowel would realistically be adhered to the abdominal wall.

Figures 11-12: Station B: Bowel Anastomosis

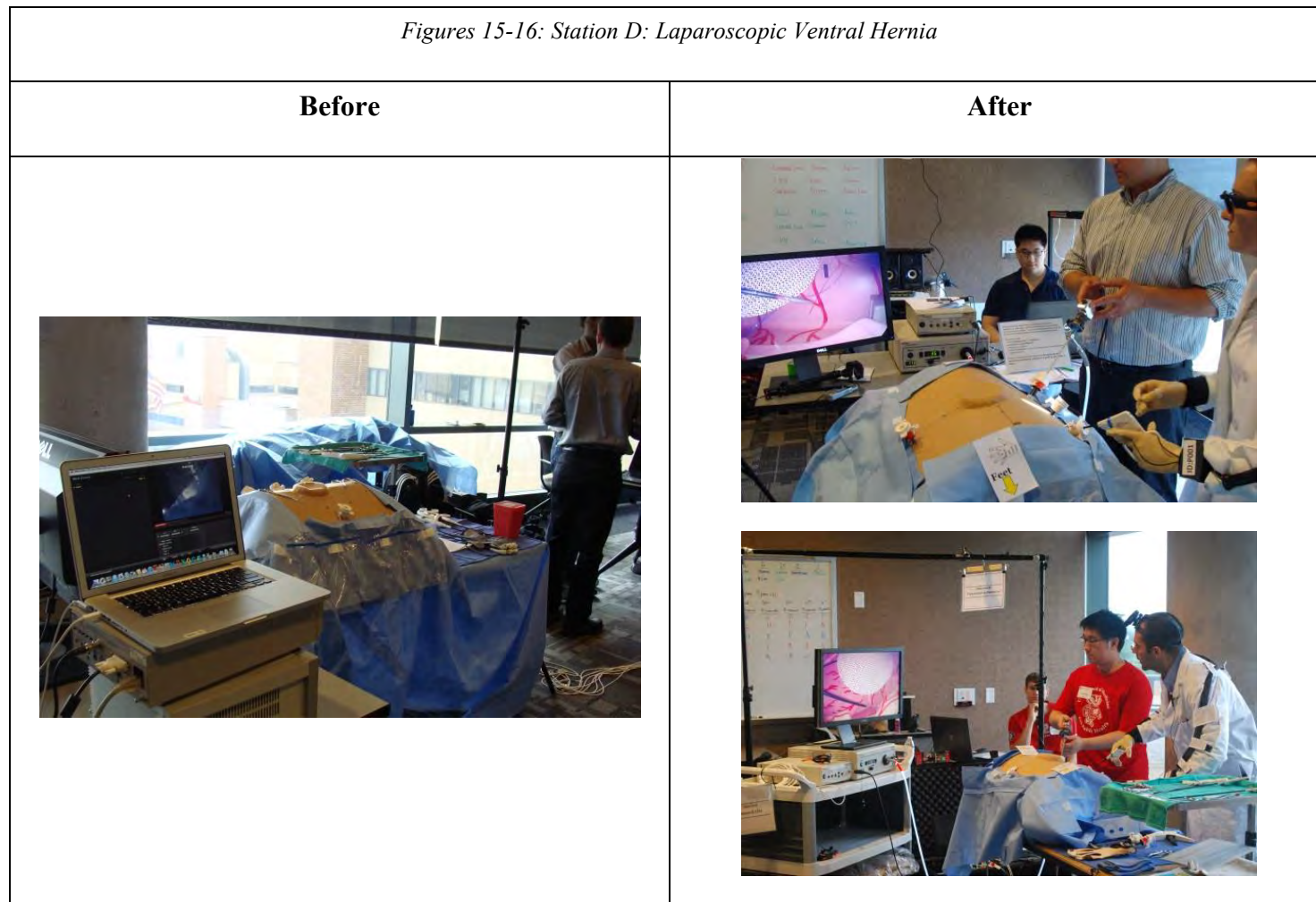


Station C: Urinary Catheter. Participants at this station require a variety of catheters spanning different sizes and configurations. There are also a number of consumable materials used during the procedure such as lubricant and sterile saline. A major improvement to the participant's ease of working in the space was the addition of a stand fixture to hold and display each of the catheter options. This provides the user with a means to see each option quickly prior to selecting one for use in the simulation. Standardized locations for the consumables containers were also selected to be within the volume captured by motion sensors and adjacent to the catheter stand.

Figures 13-14: Station C: Urinary Catheter





Station D: LVH. Early setup of this laparoscopic simulation did not meet participants' needs for availability of all necessary monitor views, visualization and identification of the workspace, and layout of instruments needed. A large monitor was added in a comfortable viewing position for the participant and researcher assistant. Various placards were strategically placed in the simulator environment to identify key landmarks and elements to the participants for their orientation to the operative environment. Standardized sets and layouts of tools were selected and provided via a Mayo stand that was placed in a location with comfortable access by the participant. The new locations of simulator elements and tools allowed the participant to make greater modifications to their procedure, such as preparing and placing additional laparoscopic ports into the model to facilitate their performance.



Sensor-containing Lab Jackets. In pilot testing, it was identified that the attachment of motion capture sensors to participants presented a great challenge for sensor placement. The attachment of the sensor wires posed an ergonomic issue for the participant's performance. To minimize ergonomic impacts and potential catching/tripping hazards, lab jackets were provided to participants for the duration of their simulations. These jackets had Velcro straps affixed to the shoulders and sleeves to facilitate rapid and repeatable attachment of sensors to individuals. The jackets also provided a means to contain and transport additional recording equipment such as the portable audio recorders used to record participants' verbal responses at each procedural station. Participants indicated that the jackets did not restrict any of their movements and provided a more realistic testing scenario.

Figures 17-18: Motion Sensor Containment

Before	After
	

These changes eliminated many of the problems noted by previous pilot participants as well as made it so the study could feasibly be conducted in a somewhat smaller space than was originally required.

The majority of these changes were implemented and tested at the third and final pilot data collection on June 6th 2014.

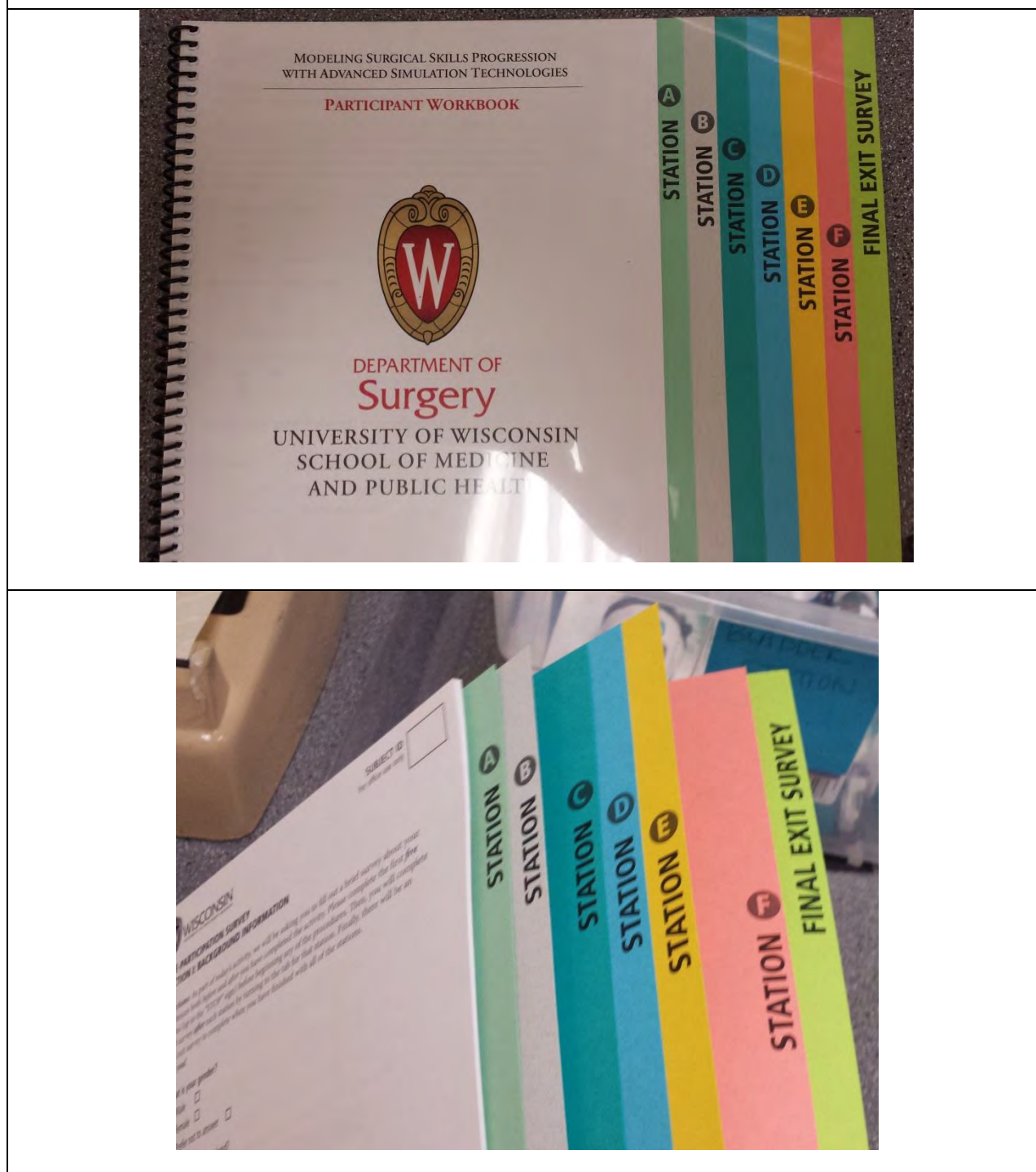
Improving Existing Study Protocols/Instructions

The second area where the research team focused their efforts was streamlining and improving the protocols and instructions for how data were to be collected at each station. These improvements included creating dedicated *Station Manager Binders*, establishing dedicated researcher responsibilities for each station, and finalizing the *Participant Survey Workbook*.

The first two items in this list are improvements to the protocol on the *researcher* side of the study, which were implemented to improve the efficiency, reliability, and validity of the team's data collection. For example, the *Station Manager Binders* provide a standardized set of instructions for how each station is to be organized, maintained, and managed, so that the station would *always* be run consistently, regardless of the researcher at that station. Also, these binders provide a centralized location (titled "Station Manager Notes") where specific incidents or phenomena that occur during a collection can be recorded for later review. The team further solidified this process by establishing precise researcher responsibility cards for each station that display the exact order of tasks each researcher is responsible for during a collection.

Similarly, the *Participant Survey Workbook* received substantial formatting changes to help improve the quality of data collection and reduce the overall demand on each participant. The spiral-bound workbook includes clarified instructions and an easy-to-navigate tabbing system for each of the post-procedure surveys. Several example images of this survey are included in the figure below, and a PDF copy of the workbook was previously submitted for your review.

Figure 19-20: Final Participant Workbook



Finally, changes were made to the way residents are tracked over the course of their participation to further improve the consistency and quality of data while reducing the demand on each participant. A custom database was created which is used to produce a series of individualized participant “Labels” used at each collection. As opposed to hand-writing or using a notecard to designate participant ID and finished products, the participant simply hands the researcher at Station B: Bowel Anastomosis, and Station D: LVH their labels which are then stuck directly to their bowel segment container and simulator skin, respectively.

Providing Training and Assessment for All Lab Personnel Who will be Involved in Data Collection

The third area of work on which the team focused was in providing organized training for any of the lab personnel who will be involved with collecting data. The individuals who had been responsible for managing each of the four clinical procedure stations at the previous two pilots were selected as “Station Team Leaders.” Together with the project and lab managers, these team leaders developed a set of structured learning objectives and training activities to prepare other lab personnel (i.e. “Station Team Members”) to fill the role as *primary* or *secondary* researcher for the stations.

The station teams engaged in *three* structured training periods: 1) initial training, 2) follow-up review and discussion, and 3) final assessment performance. The final assessment for each of the stations included a standard rubric scoring system that was used to rate each of the station team members in their ability to perform the required tasks for each researcher role.

Training of new personnel in experimenter roles

Additional student personnel were hired to supplement experimenter roles during participant data collections. Three students were trained to serve as primary and/or secondary researchers for each of the clinical scenario stations. Training was administered via the structured learning activities used to train other personnel in Quarter 2.

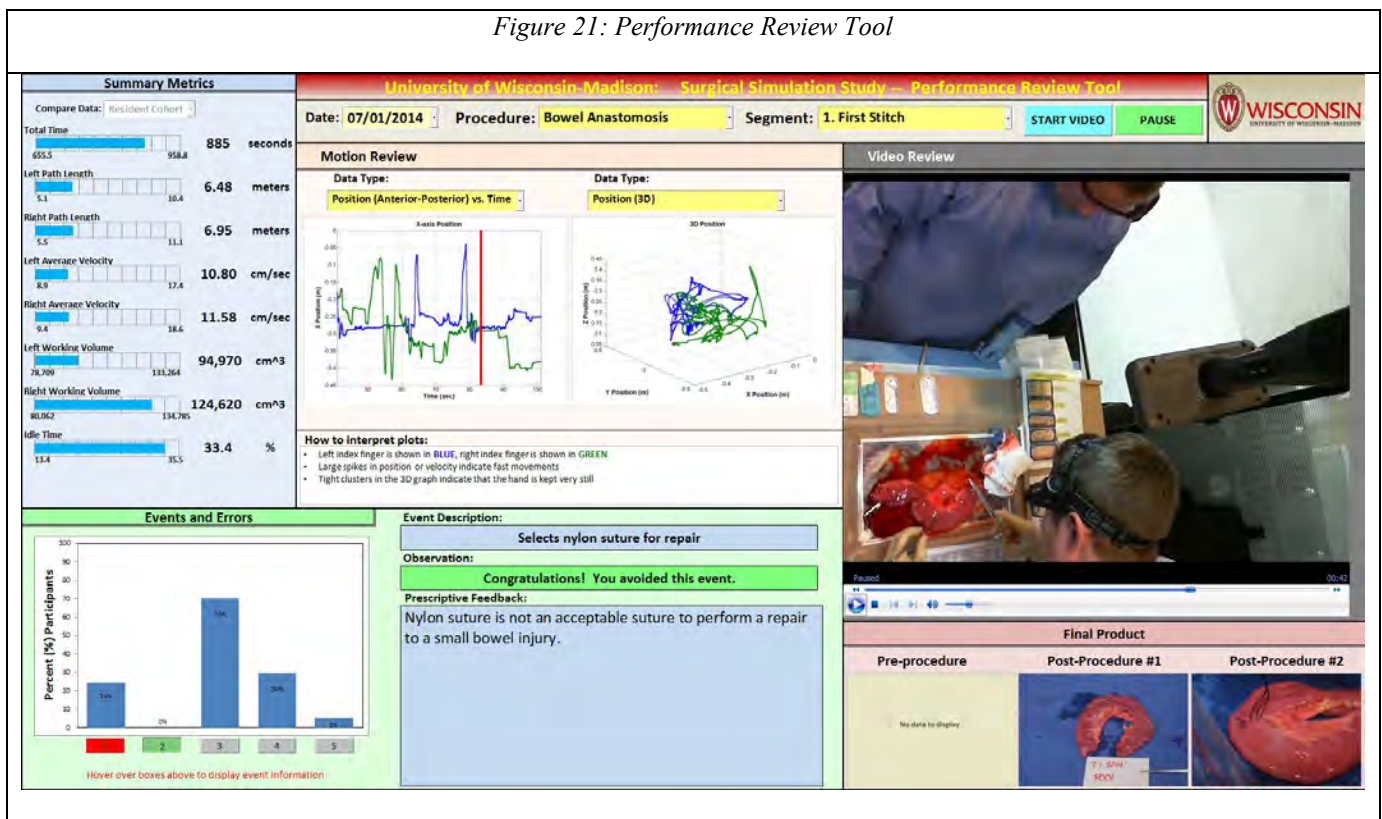
Distribution of procedure feedback to study participants

It was identified that participants in our study desired feedback about the quality of their performances after participating in our data collection sessions. Giving immediate performance feedback at data collections would lead to subjective bias in how participants perform other stations, so it was decided to give them analyzed data at a later date than the tests were performed.

For each of the simulated clinical procedures, information was analyzed and compiled for the quantitative motion data, as well as common events and errors observed for each participant and the group cohort. These metrics about their performance were presented to participants in a Microsoft Excel-based, interactive spreadsheet interface that allowed them to view metrics for each clinical station performed, and compare performance to their peer cohort. Along with these metrics, this Performance Review Tool interface presented videos of their performance, plots of their motion data, and images of their final product from their clinical scenario. The tool also gave participants prescriptive feedback on accepted methods for avoiding some of the common errors they or their peers committed during our simulations.

After these Performance Review Tools were distributed to study participants through a secure online database, we held four focus group interview sessions with past and future participants to obtain feedback about the tool. Lessons learned from these focus groups indicated which sections of the tool were found most useful and in which areas participants desired to see different forms of information. These focus groups were essential in our understanding of how to proceed with the second generation of this software tool for distributing relevant and useful feedback to our participants. This effort also aids significantly in the retention of existing and recruitment of new participants for the study.

Figure 21: Performance Review Tool



Additional Staffing (Eran Gwillim, Caitlin Jenewein, Becky Ray)

Three additional staff members have been added to the research team over the course of the last year. Each of these members bring specific backgrounds and expertise to the team, which will overall assist with addressing the grant's objectives. A brief description of each new member as well as their role in the project is provided below.

Eran Gwillim, MD:

Eran Gwillim received his MD from the University of Illinois. He is working on simulation model and station design, as well as creation of performance assessment tools and analysis of research study participant performance.

Caitlin Jenewein:

Caitlin, BS, was hired as a Research Specialist after graduating from the University of Wisconsin, Madison. Her continuing roles in the project include assisting in data collection and analysis.

Becky Ray, PhD:

Dr. Ray received her receive her PhD in Psychology and Neuroscience from Stanford University and is currently working towards her MS in Biostatistics at Pennsylvania State University. Her specific role in the project involves conducting statistical analyses and assisting in the development of data analysis protocols.

Key Research Accomplishments

Table 1 below provides a bulleted list of the project accomplishments as organized by the quarter they were achieved. Additional information such as research citations and specific achievement dates have been provided whenever they were available.

Table 1. List of Project Accomplishments per Quarter

#	Task	Quarter
1	Conducted an expert review of each of the four clinical procedure stations, which included an audio recorded interview and demonstration of each station with an accomplished attending physician or late-year resident.	One
2	Conducted a third pilot data collection and updated clinical procedure stations to address shortcomings, inefficiencies, and/or data collection changes.	One
3	Created and updated dedicated “Station Manager Binders” for each of the clinical stations, which contains all of the relevant information for correctly setting up and managing the station, inventorying its supplies, and recording any unexpected incidents relevant to the integrity of the study (e.g. simulator malfunction or participant compliance issues).	One
4	Designed, built, and piloted dedicated station fixtures, which have been custom created to simplify and consolidate each of the clinical stations as well as add to the overall professional aesthetic of the stations.	One
5	Organized the lab personnel into Clinical Station Teams whose responsibility is to be trained as an “expert” in managing one to three of the four clinical procedure stations. Each station team was trained on how to conduct an effective, consistent, and objective data collection while managing each of the clinical procedure stations. The team members were then each assessed on their ability to perform all relevant tasks and responsibilities using a standardized rubric.	One
6	Divided station data collection responsibilities into two categories to maximize the collection effort. The responsibilities are divided between running the motion monitoring software and assisting the participant in the collection; along with minor logistical steps imperative to the success of the collection time of twenty minutes.	One
7	Created a dedicated station cart for each of the six simulation stations as well as a general supplies/administrative cart and a motion-capture cart.	One
8	Created cognitive scenarios for participants to review and discuss aloud post data collection on the Central Line and the Urinary Catheterization stations.	One
9	Created a Performance Feedback Form, which will provide participants with an interactive, personal report on their performance during any number of their data collection sessions or stations.	One
10	Successfully recruited 17 participants to represent our first study cohort.	One
11	Finalized the “Station Manager Binders” to reflect best practices including a more detailed inventory and organization to the mobile units.	Two
12	Finalized the Participant Survey Workbook by adding additional, clarifying demographic questions.	Two
13	Conducted data collection from 38 residents spanning 6 different institutions. Based on experience, a total of 37 participants completed the data collection.	Two
14	Organized post collection data with a Post Participant Checklist to guarantee that all data was stored in the same method and confidentiality was ensured.	Two
15	Updated the design of the participant feedback/report card model to best fit participant outcomes.	Two
16	Dr. Pugh participated in the Medical Practice initiative IRP in Orlando, FL and gave a verbal update and presentation on the state of the project. She discussed both the accomplishments and the setbacks of the project and was well received by her peers.	Two

Table 1. List of Project Accomplishments per Quarter

#	Task	Quarter
17	Continued training and cross training additional personnel into Clinical Station Teams as the needs for scheduling the data collections changed based on locations and dates.	Three
18	Conducted data collection from an additional 9 residents from the University of Chicago, bringing the total from year one of data collection to 47 participants (46 of which completed the collection) spanning 7 institutions.	Three
19	Purchased Audio/Video transcription software Transana from Wisconsin Center for Education Research to replace MVTA coding program. Began to train staff using transcription software for continual coding and categorizing quantitative and qualitative features from verbal and video recorded data.	Three
20	Distributed the Performance Review Tool to 38 participants while the final data analysis was being conducted for the remaining 9 participants.	Three
21	Two abstracts submitted and accepted as presentations to 10 th annual Academic Surgical Congress (ASC); (Rutherford, et al, 2014; Ray, et al, 2014).	Three
22	Continued data analysis for further conference abstract and manuscript submissions.	Three
23	Began communication with William Lorie, an expert in analysis and design of survey assessments, for possible collaboration.	Three
24	Distributed the Performance Review Tool to remaining 9 participants from the University of Chicago and collected feedback on the tool in the form of an online survey.	Four
25	Dr. Carla Pugh presented the talk, “Skills of Hands and Mind: Research into Decay, Recovery & Mastery” at The International Meeting for Simulation in Healthcare meeting	Four
26	Subcontractors Felix Huang and Sandro Mussaivaldi spent 2 days in Madison (January 15 th and 16 th) working on data analysis and collaboration time line. Weekly teleconference meetings continue to occur with them both.	Four
27	The UW Department of Surgery Research Summit occurred January 21 st , 2015. The lab presented 5 posters.	Four
28	A focus group was held at ASC Meeting in Las Vegas, NV to look at recruitment efforts and the Performance Review Tool that participants were sent prior to the meeting. Meeting occurred February 2 nd - February 5 th , 2015 and a total of 8 past participants from 4 different site locations attended and provided feedback.	Four
29	Also at the ASC Meeting in Las Vegas, NV, the researchers held a booth in order to generate some interest in recruitment for the study. Three new institutions have expressed interest and are currently in contact with lab management about coming aboard to participate in the study.	Four
30	Two more focus groups were held at the UW Madison campus for additional participants that were unable to attend the primary focus group at the ASC Meeting. These focus groups had the same agenda points and were held on February 17 th (one in the morning, one in the afternoon).	Four
31	A data collection pilot is currently being planned for April 30 th , 2015 and protocol updates, survey updates, as well as station enhancements are currently underway.	Four
32	Recruitment efforts began for year two of data collection. Several institutions have expressed continued interest and will be meeting with Dr. Pugh at the ASE Meeting to develop a plan for championing the study as well as recruitment efforts.	Four

Reportable Outcomes

Table 2 provides a bulleted summary of the reportable outcomes achieved over the past year. These outcomes include specific methodological improvements, new prototypes such as the..., and also specific products such as conference presentations, research papers, assessment instruments, and research protocols. Specific citations have been provided when appropriate.

Table 2. List of Reportable Outcomes per Quarter

#	Type	Outcome	Quarter
1	Product	Fully refined virtual reality stations based on pilot feedback.	One
2	Methodology	Refined procedural protocols for all stations. Collection-specific materials and instructions created for motion monitoring. Trained and tested team in proper procedure.	One
3	Prototypes	Fabrication of simulated model fixtures to ensure data collection integrity.	One
4	Product	Created station-specific carts stocked to create smooth setup and breakdown as well as address transportation needs.	One
5	Product	Participant workbooks finalized.	One
6	Product	Improvements implemented in motion monitoring software as well as video data collection setup.	Two
7	Methodology	Standardized methods developed for equipment storage and transportation.	Two
8	Product	Training documents and protocol developed for sensor application.	Two
9	Methodology	Data archive method using UW-Madison REDCap secured database developed to expedite data entry.	Two
10	Methodology	Developed methodology for analyzing participant workbook and survey data and obtaining time stamps of video data for segmenting regions of interest in motion data.	Two
11	Product	Completed development on the initial version of the Microsoft Excel-based Performance Review Tool to send to participants. Tool contains information about their individual performance, errors observed and accompanying media of highlighted video clips.	Three
12	Product	Developed survey for participants to assess the Performance Review Tool to facilitate future enhancements to both the tool and the study.	Three
13	Product	Two presentations were accepted and presented at the Academic Surgical College (ASC) (Ray et al., 2015; Rutherford et al., 2015).	Three
14	Product	One ASC presentation was accepted as a manuscript and is under final review at the journal (Ray et al., 2015, under review). The other manuscript is in preparation (Rutherford et al., 2015, in preparation).	Four

Final Conclusions

Year two of the project has included a number of significant steps towards meeting the four key study objectives outlined by our original SoW. Specifically, the team has successfully completed the first year of data collection; refined the simulation stations for the initial and future data collections; analyzed performance on multiple stations; and disseminated our preliminary work in the form of several papers and presentations.

References for Abstracts Submitted as Part of this Project

Manuscripts

D'Angelo, A.D., Cohen, E.R., Kwan, C., Laufer, S., Greenberg, C., Greenberg, J.A., Wiegmann, D.A., Pugh, C.M. (2015). Use of decision-based simulations to assess resident readiness for operative independence. *Am J Surg*, 209(1), 132-9.

D'Angelo, A.D., Rutherford, D.N., Ray, R.D., Laufer, S., Kwan, C., Cohen, E.R., Mason, A., Pugh, C.M. (2015). Idle time: An underdeveloped performance metric for assessing surgical skill. *Am J Surg*, 209(4), 645-51.

D'Angelo, A.D., Law, K.E., Cohen, E.R., Greenberg, J.A., Kwan, C., Greenberg, C., Wiegmann, D.A., Pugh, C.M. (In Press). The use of error analysis to assess resident performance. *Surgery*.

D'Angelo, A.D., Rutherford, D.N., Ray, R.D., Mason, A., Pugh, C.M. (Under review). Operative Performance: Quantifying the surgeon's response to tissue characteristics. *Journal of Surgical Research*.

D'Angelo, A.D., Ray, R.D., Jenewein, C.G., Jones, G.F., Pugh, C.M. (Under review). Residents' perception of skill decay during dedicated research time. *Journal of Surgical Research*.

Pugh, C.M., D'Angelo, A.D., Cohen, E.R., Law, K.E., Ray, R.D., Greenberg, J.A., Greenberg, C., Wiegmann, D.A. (In preparation). Analysis of Residents' Intraoperative Error Management Strategies. Planned submission to *Annals of Surgery*.

Gwillim, E.C., Law, K.E., Rutherford, D.N., D'Angelo, A.D., Minkoff, E.C., Pugh, C.M. (Under review). Error Tolerance: A New Psychomotor Performance Metric in Laparoscopic Surgery. *Surgery*

Abstract submissions

Gwillim, E.C., Law, K.E., Pugh, C.M. Error tolerance: A new analysis approach in laparoscopic surgical simulation. Abstract submitted to the 2015 Association of American Medical Colleges Education Meeting.

D'Angelo, A.D., Law, K.E., Cohen, E.R., Ray, R.D., Shaffer, D.W., Pugh, C.M. Error Management: Do Residents Identify Errors as Reversible? Abstract submitted to the 2015 Association of American Medical Colleges Education Meeting.

Law, K.E., Ray, R.D., Pugh, C.M. A tale of two measures and their association with task outcomes: The case of psychomotor skills and self-assessment. Abstract submitted to the 2015 Association of American Medical Colleges Education Meeting.

Huang, FC, " Motor control adaptation in a simulated tissue puncture task", The Role of Human Sensorimotor Control in Surgical Robotics, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2014.

Abstract Presentations

Law, K.E., D'Angelo, A.D., Ray, R.D., Pugh, C.M. (2015, April). Penetrance of rule-based errors throughout the learning curve of LVH repair. Accepted for presentation at the annual Association for Surgical Education in Seattle, WA.

Ray, R.D., Barlow, P.B., D'Angelo, A.D., Pugh, C.M. (2015, Feb). Residents' perception of skill decay during dedicated research time. Presented at the annual Academic Surgical Congress in Los Vegas, NV.

Rutherford, D.N., D'Angelo, A.D., Kwan, C., Barlow, P.B., Pugh, C.M. (2015, Feb). Position clustering: A novel approach to quantifying laparoscopic port placement. Presented at the annual Academic Surgical Congress in Los Vegas, NV.

D'Angelo, A.D., Collier, W., Shaffer, D., Pugh, C.M. (2014, October). Intra-Operative Decision Making: Impact of the Error Recognition Process on Successful Error Recovery. Presented at the annual meeting of the Wisconsin Surgical Society, Kohler, WI.

Cohen, E.R., Maag, A.D., Kwan, C., Laufer, S., Greenberg, C., Greenberg, J. (2014, April). Use of Decision-based Simulations to Assess Resident Readiness for Operative Independence. Presented at the annual meeting of the Association for Surgical Education, Chicago, IL.

Gwillim, E.C., D'Angelo, A.D., Law, K.E., Cohen, E.R., Rutherford, D.N., Pugh, C.M. (2015, March). Error Tolerance: A New Psychomotor Performance Metric in Laparoscopic Surgery. Presented at the annual American College of Surgeons Accredited Education Institutes Consortium Meeting, Chicago, IL.

D'Angelo, A.D., Law, K.E., Cohen, E.R., Greenberg, J.A., Kwan, C., Greenberg, C., Wiegmann, D., Pugh, C.M. (2015, January). The Use of Error Analysis to Assess Resident Performance. Presented at the annual University of Wisconsin Department of Surgery Research Summit, Madison, WI.

Rutherford, A.N., D'Angelo, A.D., Kwan, C., Barlow, P.B., Pugh, C.M. (2015, January). Position Clustering: A Novel Approach to Quantifying Laparoscopic Port Placement. Presented at the annual University of Wisconsin Department of Surgery Research Summit, Madison, WI.

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D'Angelo, A.D., Cohen, E.R., Kwan, C., Laufer, S., Greenberg, C., Greenberg, J., Wiegmann, D., Pugh, C.M. (2015, January). Use of Decision-Based Simulations to Assess Resident Readiness for Operative Independence. Presented at the annual University of Wisconsin Department of Surgery Research Summit, Madison, WI.

Ray, R.D., D'Angelo, A.D., Jenewein, C.G., Jones, G.F., Pugh, C.M. (2015, January). Residents' Perception of Skill Decay during Dedicated Research Time. Presented at the annual University of Wisconsin Department of Surgery Research Summit.